

## CONSTITUENTS OF RESPONSE RATE

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Response rate and the proportion of time pigeons allocated to a key-pecking activity were measured on several basic types of reinforcement schedules. Reinforcement frequency was varied within each type of basic schedule, and the effects on two constituents of response rate were noted. *Propensity*, the proportion of time the birds spent on a platform in front of the key, showed very consistent effects as reinforcement frequency varied: in general, it decreased when reinforcement frequency markedly decreased and it increased when reinforcement frequency increased. *Speed*, key pecks per unit of time spent on the platform, showed inconsistent effects when reinforcement frequency varied. Consequently, response rate showed less consistent effects than did propensity. Cumulative response records demonstrated the existence of several different types of transitions or boundary states between the key-pecking activity and other activities. The types of transitions that occurred between activities depended on both the type of reinforcement schedule and the frequency of reinforcement. The propensity data support the position that general laws of behavior can be based on temporal measures of behavior. The speed data suggest that, if a complete assessment of the dynamic properties of behavior is to be achieved, measures of behavior must incorporate the structural variations in the operant unit.

*Key words:* response rate, propensity, speed, boundary states, key pecks, pigeons

Following the important lead of Skinner (e.g., 1938, 1966), many investigators of operant behavior have taken response rate as the basic measure of interest (see Honig, 1966; Honig & Staddon, 1977). The continuous nature of behavior, however, has prompted some researchers (e.g., Baum & Rachlin, 1969; Gilbert, 1958; Premack, 1965) to argue that the relative amount of time an organism allocates to an activity is an important behavioral measure of that activity—perhaps even more important than response rate in the sense of eventually leading to more comprehensive laws of behavior. The mathematical relationship between response rate and relative amount of time allocated to an activity can be expressed as follows (see Gilbert, 1958):

$$r = sp,$$

where  $r$  is overall response rate,  $s$  is the rate

of response per unit of time in which the activity comprising the response occurs, and  $p$  is the relative amount of time allocated to this activity. In this paper,  $s$  and  $p$  will be referred to as *speed* and *propensity*, respectively.

The issue of response measures versus time measures of operant behavior gives rise to the question of how the two constituents of response rate, speed and propensity, vary as a function of the independent variables typically manipulated in operant research. Data relevant to this question have suggested to some researchers (e.g., Gilbert, 1958; Rachlin, 1973) that speed is relatively invariant across such manipulations; hence, at best, rate is redundant to propensity and, at worst, rate is less precise than propensity because rate is affected by uncontrolled variations in speed.

There are, however, some potential problems or shortcomings associated with previous methods that have measured time allocation or propensity. For example, Gilbert (1958), using rats, and Catania (1961), using pigeons, estimated time spent in lever-pressing and key-pecking activities, respectively, by excluding interresponse times (IRTs) longer than an arbitrarily specified duration. But during some

Some of these data were presented in an invited address at the Third Annual Convention of the Midwestern Association of Behavior Analysis, Chicago, May 14-17, 1977. The research was supported by Grant No. A 7461 from the Natural Sciences and Engineering Research Council of Canada. Reprints may be obtained from either author, Department of Psychology, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2.

short IRTs, the animal may not engage in the activity of interest, and during some long IRTs it may. The extent of the resulting error is unknown and could conceivably be large. Rand (1977) used a more direct measure of propensity by relying on an experimenter to judge whether a pigeon was engaging in the key-pecking activity. The activity was defined only as head movements directed toward the key; however, the key-pecking activity, broadly defined, is not necessarily restricted to these movements. Other movements, (e.g., turning around) that occur shortly before a reinforced key peck may also become part of the key-pecking sequence because of "adventitious reinforcement" (cf. Skinner, 1948).

In certain other studies of relative time allocation, measures of speed and rate were not made. This category includes experiments on the relative amount of time a pigeon has stood on one side of an experimental chamber (Baum & Rachlin, 1969), the relative amount of time a pigeon has stood on a small platform (Bouzas & Baum, 1976), and the relative amount of time a pigeon has remained in the presence of a light of a particular color (Brownstein, 1971; Brownstein & Pliskoff, 1968). In each of these studies, the functional relationships obtained between relative time allocation and reinforcement frequency were quite similar to those found between response rate and reinforcement frequency. But this result does not necessarily imply that speed contributes little or nothing to changes in response rate. For example, systematic variations observed in the topography of the key-pecking activity during variable-interval (VI) schedules (Hearst, 1969) may affect speed and thereby contribute to the form of the relationship found between response rate and reinforcement frequency on these schedules (Cattania & Reynolds, 1968).

It might appear that the methods used in some studies on concurrent schedules directly measure both propensity and speed (e.g., Cattania, 1963; LaBounty & Reynolds, 1973). These techniques do determine the relative time spent in the presence of stimuli associated with each schedule; however, there are probably times during which the animal engages in behavior not reinforced by the programmed schedules (e.g., when the animal grooms, rests, etc.). The methods used in these

studies do not provide a direct means of extracting this time, nor can we be sure of the assumption that this time is distributed proportionally across each of the programmed schedules (cf. LaBounty & Reynolds, 1973; Baum, 1974).

In the study to be reported here, a particular behavioral control technique was used to measure directly propensity and speed in simple reinforcement schedules. The method was similar to the platform procedure of Bouzas and Baum (1976), but it also incorporated a key-pecking response. A small, thin platform was placed on the floor below the response key in a standard operant chamber for pigeons. Key pecks were reinforced only when the bird stood on the platform. To prevent actions off the platform from becoming part of the key-pecking sequence, a contingency was imposed whereby no key peck would be reinforced unless the bird had stood on the platform for a specified continuous time period. To ensure differential on-platform and off-platform behavior, the key light was red when the bird was on the platform and green when it was off the platform. Propensity was defined as the relative amount of time spent standing on the platform. Propensity, speed, and response rate were examined and compared as functions of reinforcement frequency within several basic types of simple reinforcement schedules. The purpose of this analysis was to investigate the fundamental processes underlying variations in response rate.

## METHOD

### *Subjects*

Eight male adult pigeons served: seven white Carneaux (P-111, P-112, P-121, P-122, P-123, P-131, P-141) and one Silver King (P-113). Four birds (P-111, P-122, P-131, P-141) were experimentally naive. The other birds had previously participated in an autoshaping experiment. All birds were maintained at 80% of their free-feeding weights throughout the study.

### *Apparatus*

A standard three-key pigeon chamber with interior dimensions 48 cm by 35 cm by 29 cm was used. Only the right key was operative; it was activated with a minimal force of .21 N. This key, mounted 24 cm above the floor, was

3 cm in diameter and could be illuminated either red or green. A 12.5 cm by 10.0 cm platform, .2 cm thick, was located 4 cm from the front panel on the grid floor below the right key. Microswitches beneath the platform were activated when a downward force of .80 *N* was applied to the platform. An opening for presenting a food hopper was located at the base of the front panel, directly below the center key. The feeder aperture could be illuminated when the feeder operated. Reinforcer presentations consisted of 3-sec access to the food tray which contained Purina Racing Pigeon Checkers.

Two miniature lamps shining through a strip of white Plexiglas provided general diffuse illumination of the chamber. An exhaust fan continuously provided fresh air and a partial masking noise to the chamber. White noise was also present in the room where the chamber was located.

#### *Procedure*

*Preliminary training.* Birds were magazine trained by first continuously operating the food hopper until they approached and consumed grain from the hopper. The feeder light was illuminated when the hopper operated. The duration of each hopper operation was gradually reduced until the birds would approach and consume grain from the hopper within 3 sec of its presentation. Then the intensity of the feeder light was gradually decreased until no light was present to prevent conditioned reinforcement properties of changes in feeder-light illumination from generalizing to subsequent changes in key-light color.

After magazine training was completed, the response key was continuously illuminated red. Key pecking was shaped and then maintained for one session on a continuous reinforcement schedule. A sequence of variable-interval schedules followed; they included VI 10-sec (one session), VI 30-sec (one session), VI 60-sec (2 to 4 sessions).

Platform training was then initiated. When the bird was off the platform the key light was green. When the bird stood on the platform, so that its weight activated the microswitches underneath, the key light changed to red. The first peck to the red key after the bird had stood on the platform for a minimum of eight consecutive seconds was

reinforced. This changeover delay (COD) was initiated each time the bird stepped on the platform and immediately after feeder operations. The COD was used to restrict the key-pecking activity to the area defined by the platform. During feeder operations, the key light always remained red. Platform training lasted 4 sessions and each session terminated after approximately 60 feeder operations.

*Experimental procedures.* During experimental procedures, the operating characteristics of the COD and key lights were the same as during platform training. However, key pecking was now reinforced on one of four basic schedules of reinforcement: variable interval (VI), fixed interval (FI), variable ratio (VR), and fixed ratio (FR). Each bird received prolonged exposure to several values of one of these basic schedules. For the VI and FI birds, the initial schedules studied (VI 1-min and FI 1-min) were introduced immediately after preliminary training. For the VR and FR birds, the initial schedules studied (VR 100 and FR 100) were introduced by gradually increasing from low to high ratio schedule values after preliminary training. Over the course of the study, the reinforcement frequencies of the basic schedules were manipulated. Figures 1 through 3 show the order and duration of these conditions. In the last phase, all birds received a number of extinction sessions. The platform and key lights operated as they had before, but the feeder did not operate throughout this phase. Session length was always 1 hr.

The various VI schedules were generated by a standard VI tape programmer and a random probability generator (BRS/Foringer). The tape programmer drove a VI 10.5-sec tape with intervals ranging from 3 to 18 sec in 3 sec steps. The sequence of intervals was randomized, and each interval had an equal probability of occurrence. Outputs from the tape programmer were fed into the probability generator. The mean of the VI schedule was determined by the setting on the probability generator.

For each session, the amount of time the bird stood on the platform and its number of key pecks while on the platform were recorded. These data were not recorded during feeder operations. Feeder operation time was subtracted from session time in calculating propensity, speed, and response rate. Key pecks

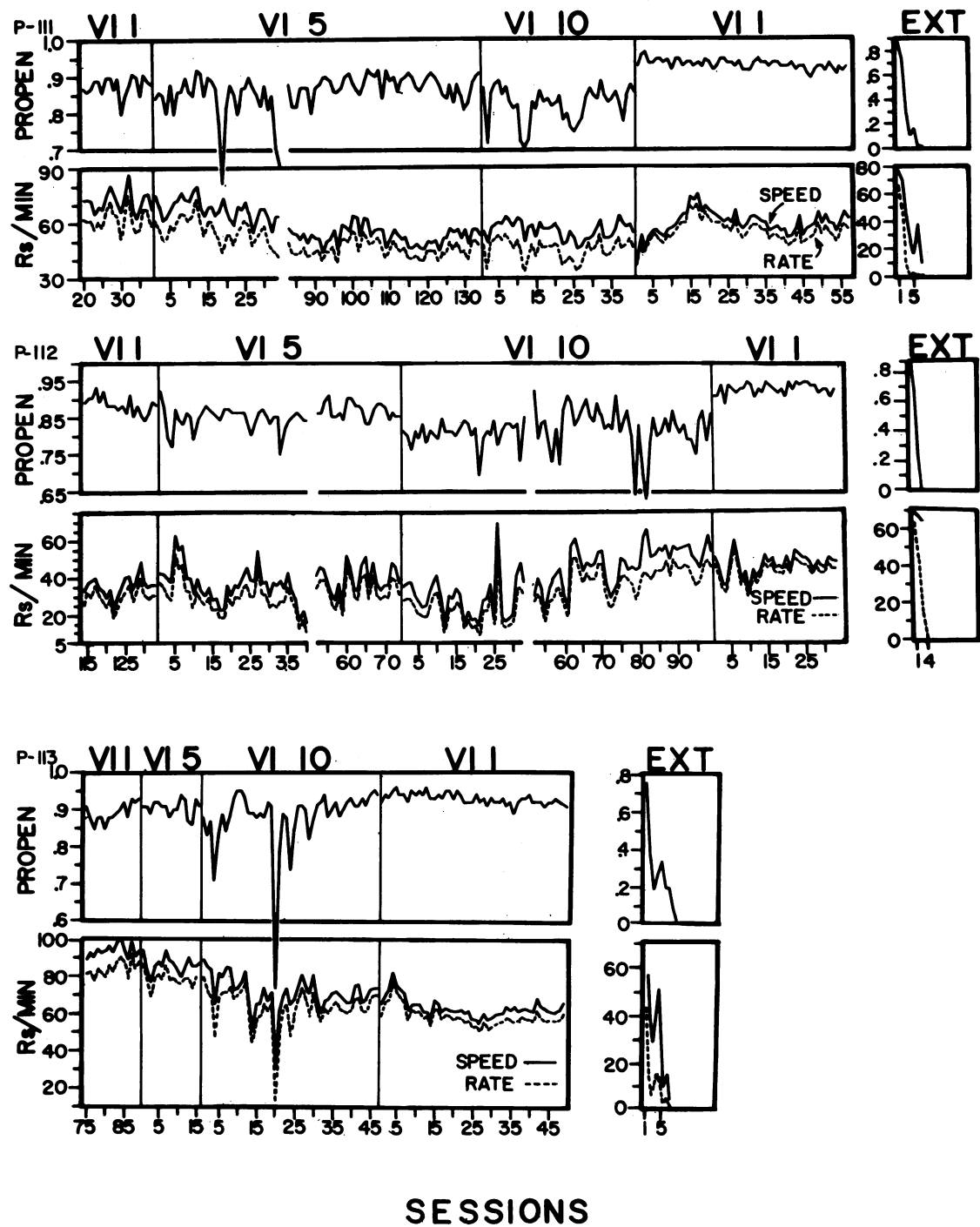


Fig. 1. Overall session-to-session data of propensity, speed, and rate during VI 1-min, VI 5-min, VI 10-min, and extinction for P-111, P-112, and P-113.

off the platform were recorded separately and did not enter into the computation of speed or response rate. Cumulative records of key pecking were taken during most sessions.

## RESULTS

### *Overall Session-to-Session Data*

*Variable-interval schedules.* Figure 1 shows the overall data for the three birds that were exposed to VI schedules. The top panels for each bird show the values of propensity obtained over sessions. The bottom panels show the corresponding values of speed and rate. In order to conserve space, certain sessions have been omitted from the figure.

Note that during the stable state for VI 1-min in Phase 1, propensity values were very similar for all birds (the range was from about .85 to .95, with considerable overlap between birds). With the change from VI 1-min to VI 5-min, propensity for P-111 and P-112 showed two rather immediate effects: (a) increased variability, and (b) an overall decrease below the baseline level obtained on VI 1-min. On a few sessions, propensity for these two birds dropped to very low levels, then quickly returned to the higher levels over the next one or two sessions. Over a large number of sessions, the variability and absolute value of propensity for these two birds tended to return to the VI 1-min baseline levels.

P-113 showed little or no change in propensity when the schedule was changed from VI 1-min to VI 5-min. However, P-113 did show an almost immediate decrease in propensity and increase in the variability of propensity when the schedule was changed to VI 10-min. By the end of the VI 10-min phase, both of these variables for P-113 had recovered their original VI baseline values. P-111 and P-112, which had exhibited these effects during the VI 5-min phase, developed no such tendency to recover on VI 10-min. Thus, the effects on propensity of instating VI 10-min for P-113 were quite similar to the effects on propensity of instating VI 5-min for P-111 and P-112. It appears, therefore, that these effects on propensity of decreasing VI reinforcement frequency were replicable across birds provided that the schedule changes were sufficiently large.

On the reinstatement of VI 1-min, propensity immediately increased to (or, in the case

of P-113, remained at) a level slightly above that at which it stabilized during the initial VI 1-min baseline phase. Correspondingly, the variability of propensity was attenuated for all birds.

The top right panel for each bird in Figure 1 shows the effects of extinction on propensity over sessions. (Note the change in scale on the vertical axes of these graphs.) On the first session of extinction, each bird manifested a slight drop in propensity below its stable level in the previous phase. Propensity then decreased rapidly and reached zero over a period of 4 to 9 sessions for all birds. A key peck was accidentally reinforced on the fourth session of extinction for P-113. This may account for the fact that propensity for this bird required the largest number of sessions to reach zero.

In contrast to propensity, speed and rate evinced little consistency either within or across the three birds. Both variables seemed to require much more time to reach stability (as determined by visual inspection of the data over blocks of 15 sessions) on the initial VI 1-min than did propensity. In addition, whereas propensity values overlapped considerably during steady-state VI 1-min, speed and rate each stabilized at different levels for these birds. More important, perhaps, is the fact that changes in reinforcement frequency did not produce clear or consistent effects on either speed or rate. When VI 5-min was instated, speed and rate showed gradual decreasing trends for P-111, initial increases followed by an eventual return to levels at or near their original VI 1-min baselines for P-112, and rather abrupt decreases to fairly stable levels for P-113. When VI 10-min was instated, similar inconsistencies in speed and rate occurred between birds. Speed and rate showed little change for P-111, increased to levels considerably above their original VI 1-min baselines for P-112, and showed a fairly gradual decreasing trend for P-113. Perhaps, however, the most significant differences between these two variables and propensity was reflected in the fact that, on the reintroduction of VI 1-min, all birds failed to recover their original VI 1-min baselines for speed and rate. This result contrasts with the immediate establishment of the slightly above baseline levels obtained with propensity on the reintroduction of VI 1-min.

On the first session of VI extinction, P-111 and P-112 manifested increases in both speed and rate above their stable levels in the previous phase; however, P-113 showed decreases in both of these variables. This again contrasts with the consistent effects in propensity (in this case a slight drop) that occurred across all three birds when the extinction schedule was introduced. Over subsequent extinction sessions, however, rate decreased rapidly to zero as did propensity. Speed, on the other hand, decreased to low levels for P-111 and P-113 and remained high for P-112. Of course, after propensity reaches zero there is no mathematically defined value for speed.

*Fixed-interval schedules.* Figure 2 shows the overall data for the three birds that were exposed to FI schedules. Note that during the stable state for FI 1-min, propensity values across birds were very similar, as they were under VI 1-min. The stable state propensity values for FI 1-min ranged between about .60 and .70, more than 10 percentage points lower than the stable levels attained under VI 1-min.

With the change from FI 1-min to FI 5-min (actually, FI 4.83 min), propensity demonstrated consistent changes. For all birds, there were immediate large increases in propensity and its variability. Then, over many sessions, propensity gradually decreased to levels below the FI 1-min baseline levels. These results contrast markedly with the immediate decrease in propensity and gradual recovery obtained with decreases in VI reinforcement frequency. However, as was found in the VI data, a decrease in FI reinforcement frequency produced a large increase in the variability of propensity. This increased variability was much larger for FI, however, and it appeared to assume a cyclical pattern which gradually "dampened out" over many sessions.

On the reintroduction of FI 1-min, propensity for all birds immediately increased to levels (.8 or slightly higher) considerably above the original FI 1-min baseline levels. With further exposure to FI 1-min, propensity gradually decreased to the original FI 1-min baseline levels for P-121 and P-122 and to slightly below the original FI 1-min baseline level for P-123. P-123 was the only bird in this study that did not demonstrate a full reversal on propensity upon reinstating a higher reinforcement frequency.

On the first session of FI extinction, propensity increased for all three birds. Propensity then decreased to zero over a number of extinction sessions.

In contrast to propensity, speed and rate evinced little consistency either within or across birds during the FI schedules. Whereas propensity values were very similar across birds during the initial FI 1-min, speed and rate each stabilized at different levels across the three FI birds. When FI 5-min was instated, P-121 and P-123 showed immediate and large increases in both speed and rate, but P-122 showed little or no increase in either variable. P-121 and P-122 then showed over many sessions a gradual decrease in both rate and speed, with cyclicity occurring similar to that which occurred for propensity. For P-123 rate also decreased and showed cyclicity, but speed remained relatively constant throughout FI 5-min. By the time that stable state performance was reached on FI 5-min, response rate had decreased relative to the FI 1-min baseline level for P-121, had increased for P-123, and had remained the same for P-122. Speed, on the other hand, was either at or above the FI 1-min baseline levels. Cyclicity in speed and rate was still present.

On the reinstatement of FI 1-min, speed and rate initially increased for P-122 but decreased for the other two birds. After these initial effects, speed and rate gradually decreased for all three birds. However, by the end of FI 1-min, only P-122 had recaptured its original FI 1-min baseline level for speed and rate. For the other birds, speed and rate had stabilized either well below (P-121) or well above (P-123) their original FI 1-min baseline levels.

During FI extinction, speed and rate initially increased for all birds. Rate then tracked propensity by decreasing to zero. Speed, however, dropped slightly for P-122 and P-123 and decreased close to zero for P-121.

*Variable-ratio schedules.* Figure 3, top, shows the overall data for the bird that was exposed to VR schedules. Since only data from this one bird are available, it is not possible to state their representativeness for VR schedules. However, several of the findings reported here replicate those obtained with VI and FI schedules.

During the initial VR 100 schedule, propensity stabilized at high values—in this case

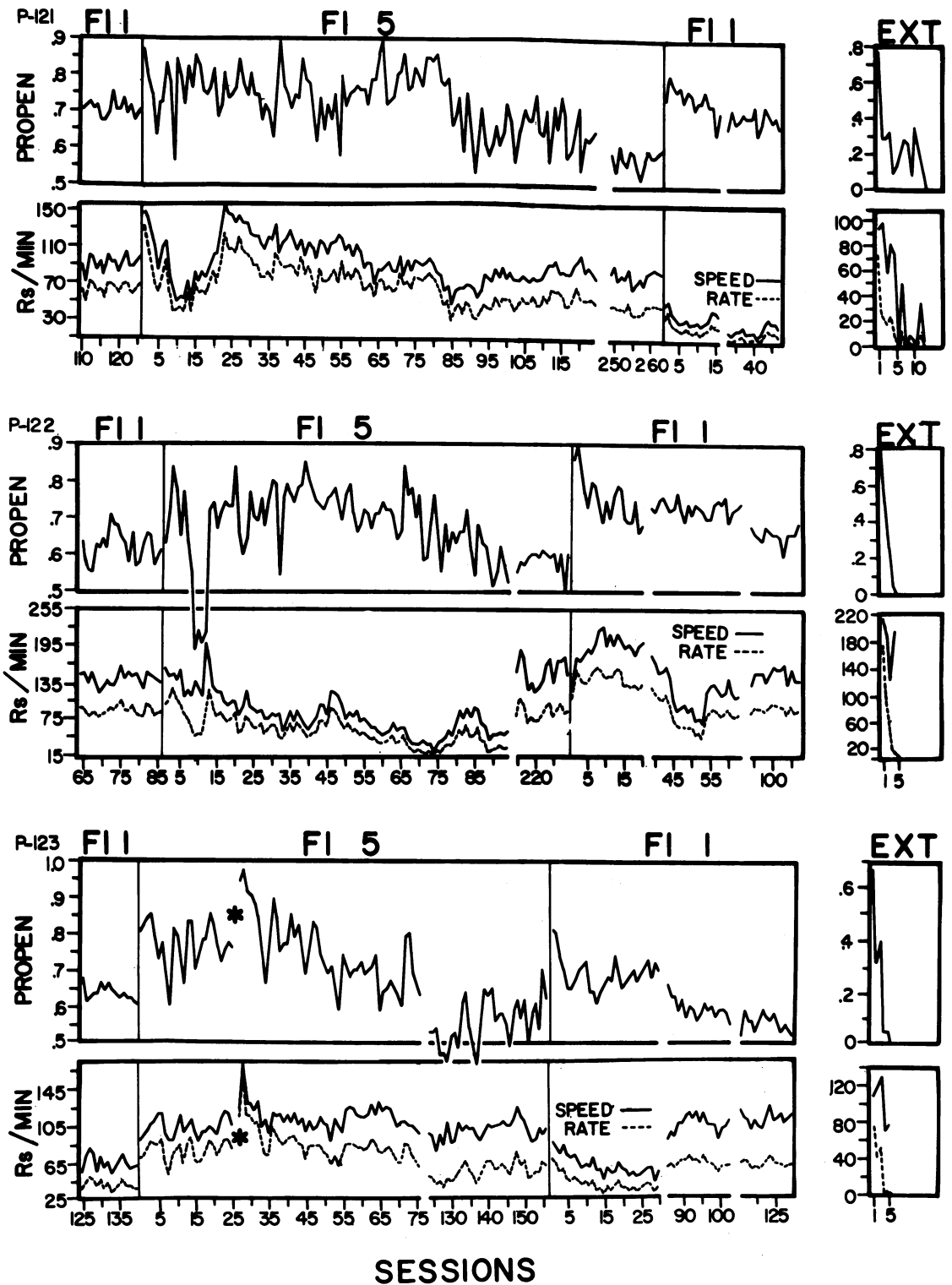


Fig. 2. Overall session-to-session data of propensity, speed, and rate during FI 1-min, FI 5-min, and extinction for P-121, P-122, and P-123. (Note: the asterisk in the data for P-123 indicates an equipment failure.)

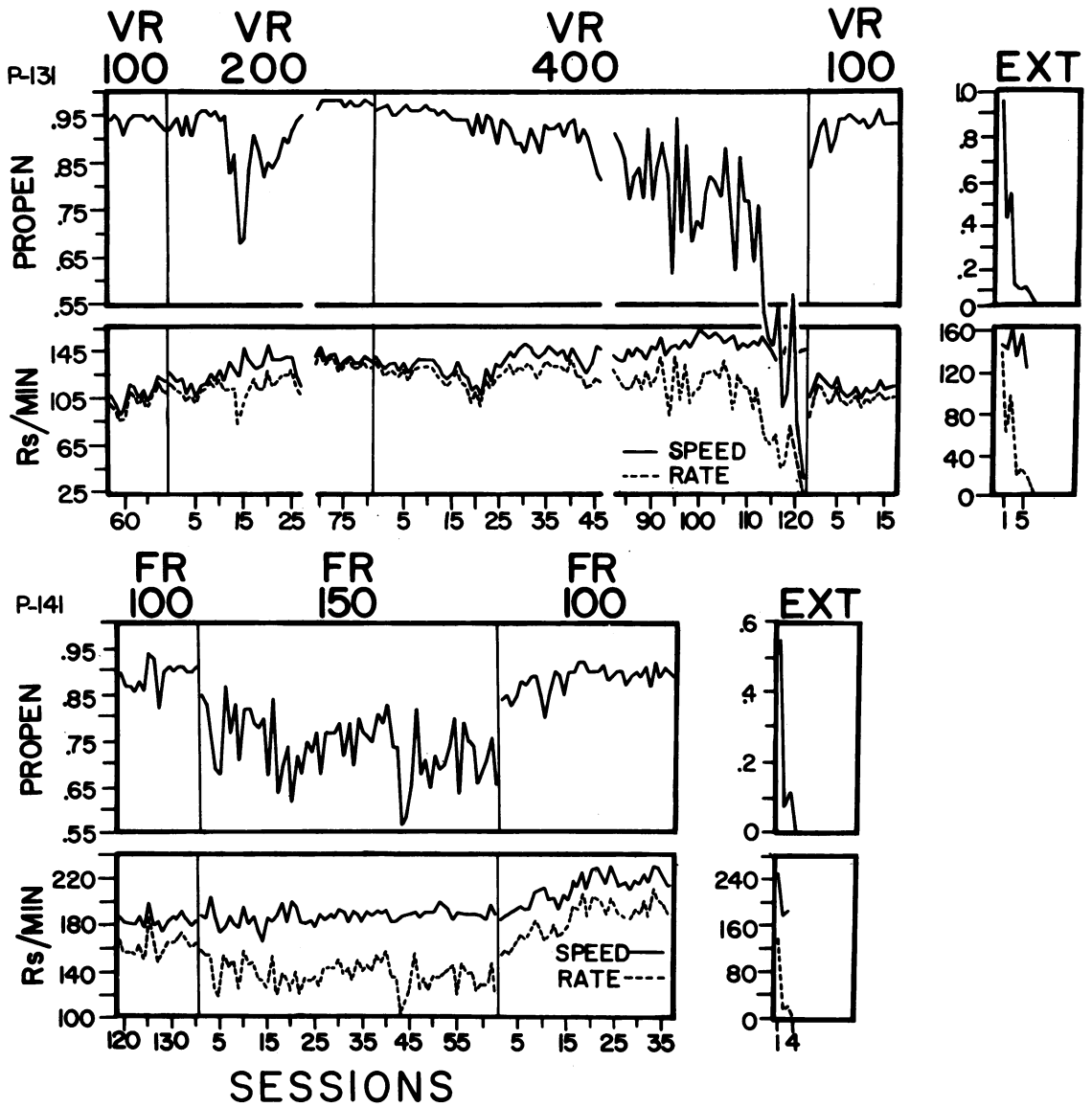


Fig. 3. Overall session-to-session data of propensity, speed, and rate during VR 100, VR 200, VR 400, and extinction for P-131, and FR 100, FR 150, and extinction for P-141.

between .90 and .95. When VR 200 was instated, propensity remained constant for about ten sessions. Then there was a sharp drop, followed by a steady recovery to a level slightly above the original VR 100 baseline level. Except for the delay in the drop in propensity and the relatively rapid recovery, this was similar to the drop and recovery in propensity that resulted from decreases in VI reinforcement frequency. Instating VR 400 after

VR 200 resulted in little or no immediate change in propensity. However, propensity eventually dropped toward zero with no indication of recovery, at which point the phase was terminated. This differed drastically from the results obtained with the interval schedules when reinforcement frequency was decreased. However, as was the case with the interval schedule when reinforcement frequency was increased to a previous high level, pro-



propensity immediately increased and eventually stabilized at the original VR 100 baseline level when VR 100 was reinstated. Then over a number of extinction sessions, propensity decreased steadily to zero.

The corresponding results for speed and rate appear to be more consistent than they were for the other birds of this study. Speed tended to be inversely related to reinforcement frequency. In addition, changes in rate tended to track changes in propensity fairly closely. Of particular interest is the fact that rate immediately returned to the original VR 100 baseline on the reinstatement of VR 100. Of all the basic schedules examined in this study, this was the only case in which the original baseline for rate was immediately recaptured.

*Fixed-ratio schedules.* The bottom half of Figure 3 shows the overall data for the bird that was exposed to FR schedules. Several findings can be noted which replicate those found for the other schedules.

During the initial FR 100 schedule, propensity stabilized at a high value—between .85 and .90. When FR 150 was instated, there was a drop in propensity and an increase in its variability. As in the case of VI, the drop was immediate. However, propensity then stabilized at the level of its initial drop. With the reinstatement of FR 100, there was an immediate and large increase in propensity, followed by a gradual continued increase to the original FR 100 baseline level. Then propensity decreased steadily to zero over a number of extinction sessions.

During the initial FR 100 schedule, speed stabilized at a very high level. With the instatement of FR 150, speed did not change from its previous baseline level on FR 100. However, with the reinstatement of FR 100, speed gradually increased to a level that was considerably above its original FR 100 baseline level. During extinction, speed increased slightly and then dropped to its original FR 100 baseline level.

Since rate tracks propensity when speed is constant, there was an immediate drop in rate and an increase in its variability when FR 150 was instated. Rate then stabilized at the level of its initial drop. With the reinstatement of FR 100, however, rate increased above its original FR 100 baseline level as had speed.

During extinction, rate tracked propensity closely.

#### *Within-Session Data*

The overall data by themselves do not give a complete picture of how the variables of interest—rate, speed, and propensity—varied as a function of the schedules examined in this study. To supplement the overall data, within-session cumulative records were taken throughout the study. Besides providing additional detailed information relating response rate to propensity and speed, the within-session data were also important in confirming (a) that time spent standing on the platform was a valid measure of the key-pecking activity and (b) that the method employed replicated well-known within-schedule effects on response rate. Meeting both of these conditions is important in generalizing from the results of this study to basic processes operating in more traditional studies of response rate.

Representative within-session cumulative records are presented under three headings: steady state performance, transition states, and extinction.

*Steady state performance.* The last 15 sessions of exposure to each schedule constituted steady state performance for that schedule in that no systematic changes in overall rate, speed, propensity (Figures 1 through 3) or in within-session patterns of responding could be detected across those sessions. Figure 4 shows representative standard cumulative response records of steady state performance on VI 1-min, VI 10-min, FI 1-min, and FI 5-min. When the bird was not on the platform, the cumulative response pen was deflected downward. Key pecks were recorded whether the bird was on or off the platform, although very few occurred in the latter case. Reinforcements are indicated by arrow heads. Each record shows an entire session from the stable state of the indicated schedule.

Note that VI 1-min produced a linear pattern of responding with few pauses, which is typical of rich VI schedules (Ferster & Skinner, 1957, pp. 333-339). When key pecking occurred, the bird was almost always on the platform; when it did not occur (i.e., during pauses), the bird was always off the platform. This indicates that time on the platform was

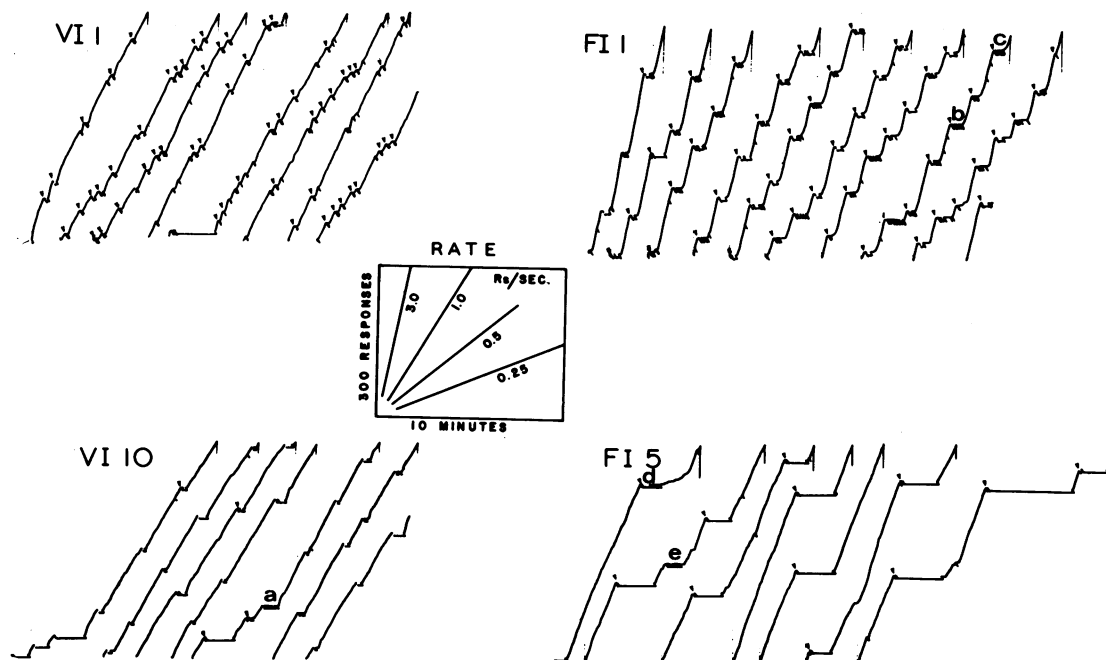


Fig. 4. Rate cumulative records of stable state VI 1-min (sess. 35) and VI 10-min (sess. 19) performance of P-111, and stable state FI 1-min (sess. 121) and FI 5-min (sess. 243) performance of P-121.

a valid measure of time engaging in the key-pecking activity.

Generally, the transitions between the key-pecking activity and activities off the platform were abrupt for VI 1-min. Sometimes, however, the birds oscillated between these two types of activities for short periods of time. This is indicated by the tracings made by the pen flicking up and down, and hence is called "flickering." As can be seen from the figure, flickering on VI 1-min, when it occurred, was generally confined to very brief time periods immediately following reinforcement.

VI 10-min also produced a linear pattern of responding but with longer pauses. As during VI 1-min, when key pecking occurred the bird was on the platform and when it did not occur the bird was off the platform. Transitions between the on-platform and off-platform activities were generally more abrupt (i.e., less flickering occurred) during VI 10-min than during VI 1-min. Some flickering still occurred, however; for example, one relatively long stretch of flickering can be seen at point *a* in the figure.

FI 1-min produced predominantly a "break-run" pattern of responding (i.e., a pause after

reinforcement followed by a rapid transition to a high steady rate of key pecking until the next reinforcement) which is the typical result of long exposure to a relatively rich FI schedule (Ferster & Skinner, 1957, Fig. 150, Record C, p. 158). There were also, however, a few instances of scalloping (i.e., a gradual acceleration to a high terminal rate) that is also typical. During the postreinforcement pauses (PRPs) the bird was generally off the platform. PRPs were generally longer during FI 1-min than during VI 1-min.

Flickering occurred more frequently and for longer periods of time during FI 1-min than during VI 1-min. On FI 1-min, it was restricted to the PRP and occasionally occurred throughout the duration of the PRP (e.g., see points *b* and *c* in the figure).

Visual observation indicated that systematic changes in the activities of the birds occurred throughout the interreinforcement interval during FI. Immediately after a feeder operation, the birds were off the platform for a period of time. During this time, the birds were either preening, wing flapping, walking about, or simply standing motionless. Then, as indicated by the flickering on the cumula-

tive records, the birds oscillated on and off the platform. They eventually remained on the platform and initiated head movements toward the key. However, as indicated by the short pauses on the platform just before key pecking, these head movements did not necessarily result in key pecks. Note that even though a pause may have been recorded at these times, the occurrence of these head movements implies that at least some part of the key-pecking activity was occurring. The area spanned by the key-pecking motions then moved either abruptly or gradually close to the response key, and key pecking commenced. An abrupt change in the pattern of head movements appeared to be associated with a break-run response pattern, whereas a gradual change appeared to be associated with a scallop pattern.

FI 5-min produced longer PRPs than did FI 1-min. Again, the effects on rate are typical of those obtained previously after long exposure to similar schedules (Ferster & Skinner, 1957, p. 159, Fig. 152). Note that while a break-run pattern appeared to be predominant, there were some instances of scalloping and also some instances of negative acceleration before the "run" part of the pattern. Such instances of negative acceleration have been termed "knees" (Ferster & Skinner, p. 160). In some intervals slight negative acceleration preceded reinforcement, as others have found with stable state FI (Cumming & Schoenfeld, 1958; Skinner & Morse, 1958).

During FI 5-min, as with the other schedules represented in Figure 4, when the key pecking activity (or its components) occurred, the bird was on the platform, and when it did not occur, the bird was off the platform. Transitions between the key-pecking activity and activities off the platform tended to be much more abrupt—i.e., less flickering occurred—during FI 5-min than during FI 1-min. As can be seen at point *d* of the FI 5-min record, however, some flickering still occurred occasionally during a PRP. In addition, flickering was not restricted to the PRP as it was during FI 1-min. For example, at point *e* flickering can be seen immediately following a knee.

Both the FI 1-min and FI 5-min rate records demonstrate that within-session fluctuations in response rate (e.g., scallops) are at

least partly attributable to corresponding fluctuations in speed—i.e., rate variations while the bird is standing on the platform. The extent to which response-rate fluctuations might also be related to within-session fluctuations in propensity is a question that is addressed in the next figure.

Figure 5 shows a representative propensity record of steady state performance on FI 1-min. As with a standard cumulative record, session time was recorded along the horizontal axis. However, time spent standing on the platform, rather than key pecks, was recorded along the vertical axis. Therefore, the slope of the line at any given point indicates the propensity at that point. Reinforcements are indicated by downward deflections of the pen. The record is from one entire session. Note that effects similar to those seen on an FI rate record can be seen in this FI propensity record. For example, a pronounced scallop pattern can be seen at point *a*, and break-run patterns and knees can be seen throughout the record. The gradual changes in propensity, the scallops and knees, resulted mainly from the flickering behavior described previously.

Propensity records of the other schedules were taken also but are not shown because their essential features are entirely obvious from the corresponding rate records. Both VI 1-min and VI 5-min produced very linear propensity records; and FI 5-min produced very consistent break-run patterns and an almost complete absence of any type of gradual acceleration.

Figure 6 shows representative rate records of steady state performance on VR 200 and FR 150. The operating characteristics of the cumulative recorder were the same as for Figure 4.

VR 200 produced high, steady rates with little pausing, as is typical of VR behavior (Ferster & Skinner, 1957, p. 398, Fig. 479). Very brief pauses occurred immediately after reinforcement, and flickering usually occurred throughout these PRPs. Occasionally, as in the first segment of the VR record, a relatively long pause occurred. Except for engaging in some flickering, the bird was always off the platform during these long pauses.

FR 150 produced pronounced PRPs followed by high, steady rates until the next re-

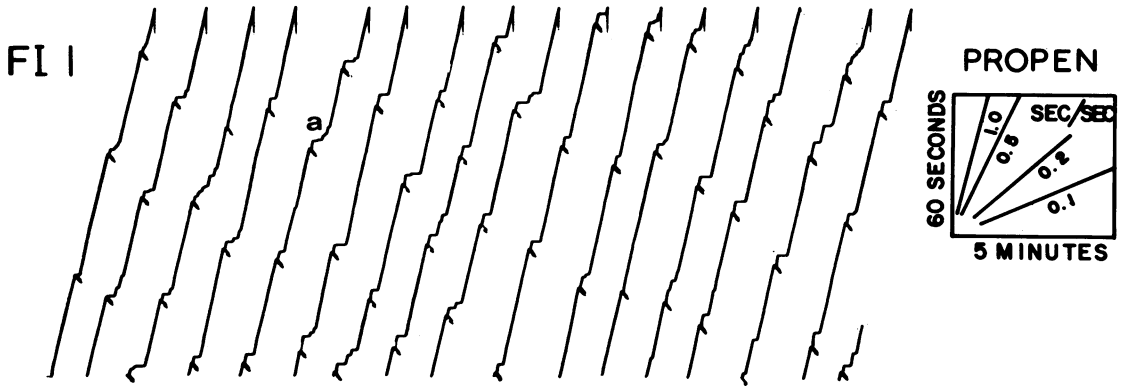


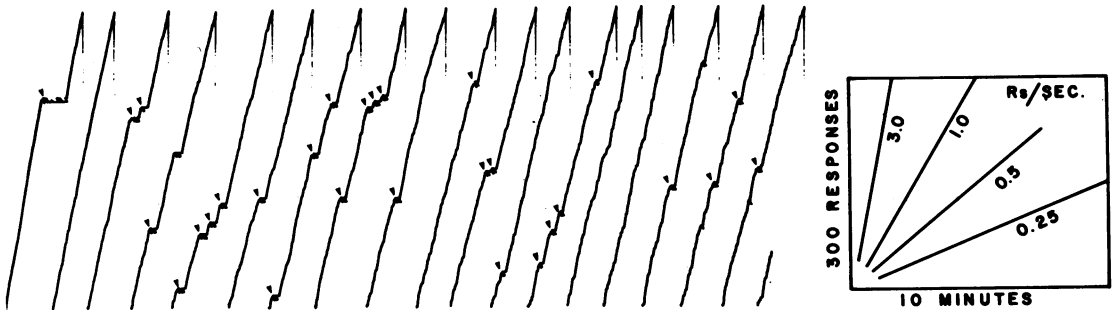
Fig. 5. Propensity cumulative record of FI 1-min for P-121.

inforcement as is typical of FR schedules. Longer PRPs occurred on the higher FR schedule as is also typical (Ferster & Skinner, 1957, pp. 48-51, Figs. 22 & 23). The bird was generally off the platform throughout almost all of the duration of the PRPs, especially long PRPs. Flickering sometimes occurred toward the end of the PRP.

*Transition states.* This section highlights some of the consistent within-session effects that were observed when a schedule change occurred and the behavior was adjusting to the new schedule.

The records in Figures 4 and 6 are called rate records because variations in their slopes indicate moment-to-moment variations in re-

### VR 200



### FR 150

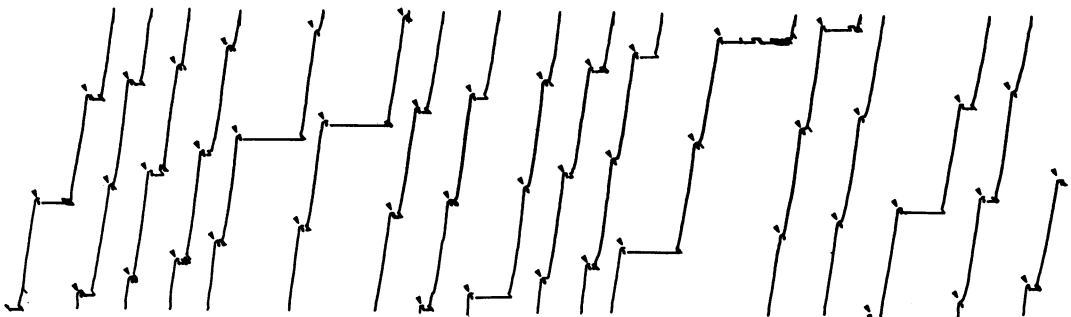


Fig. 6. Rate cumulative record of stable state VR 200 (sess. 76) performance of P-131, and stable state FR 150 (sess. 65) performance of P-141.

sponse rate. It is also possible to take speed records in which moment-to-moment variations in the slope indicate moment-to-moment variations in speed. This is done by modifying the operation of a standard cumulative recorder so that, while key pecks are recorded in the usual manner, time is recorded only when the bird is standing on the platform. Figure 7 shows rate and corresponding speed records from the 2nd and 12th sessions of VI 10-min after VI 5-min for P-111. Only the first two-thirds of each session are shown. For the speed records, an infinite slope indicates that the bird was pecking the key while off the platform, since key pecks were recorded whether or not the bird was on the platform. Reinforcements are indicated by downward deflections of the response pen.

Long pauses, during which the bird was off the platform, characterize the rate record during Session 2 of VI 10-min. Speed was relatively constant throughout the session. By Session 12, the long pauses in the rate record had largely given way to numerous short pauses, usually exhibiting a good deal of flick-

ering. The behavior was quite unstable and contained occasional instances of off-platform key pecking (see the circled portions of the record, Figure 7). Nevertheless, speed, although somewhat lower on Session 12 than on Session 2 of VI 10-min, remained very constant throughout Session 12. Eventually, after a number of sessions, a more steady rate, with less frequent pausing and flickering, prevailed (see the VI 10-min record in Figure 4).

Figure 8 shows the development of FI 5-min behavior following FI 1-min for P-123. Selected rate records are on the left, and the corresponding speed records are on the right. Each record is from an entire session. The rate records will be described first.

The left side of Section A shows the rate record from Session 2. The record initially displays short PRPs and a linear pattern of responding throughout the remainder of each interreinforcement interval. As the session progressed, short off-platform pauses prior to the end of the interval occurred with increasing frequency. In the latter part of the session, pronounced negative acceleration was present

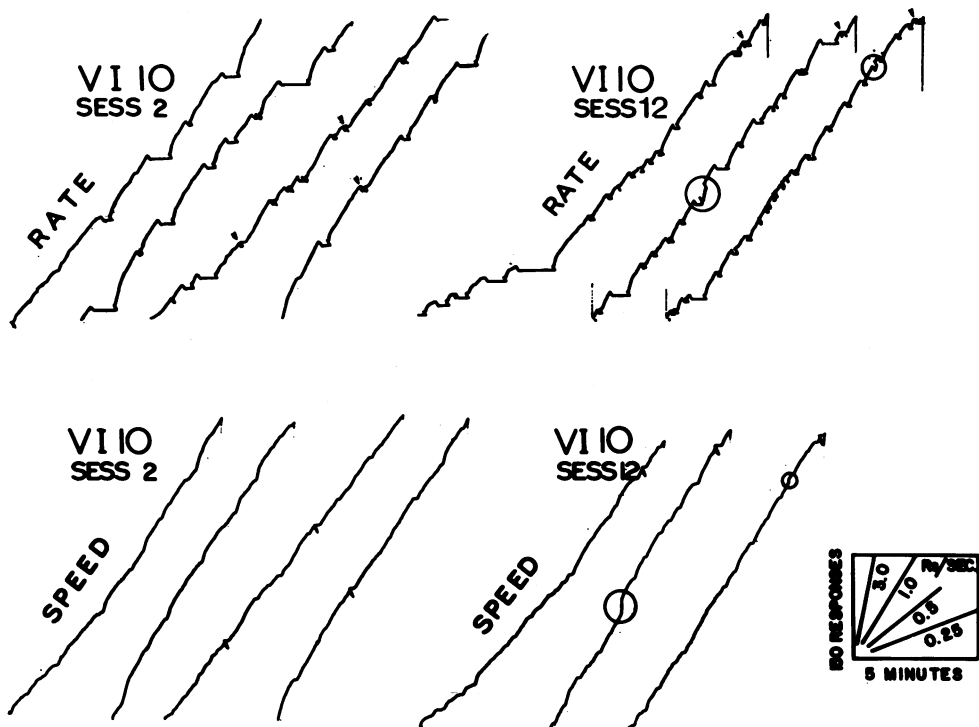


Fig. 7. Rate and speed cumulative records of early VI 10-min performance following VI 5-min for P-111. Only the first two-thirds of each of the indicated sessions are shown. The circles indicate off-platform key pecking.

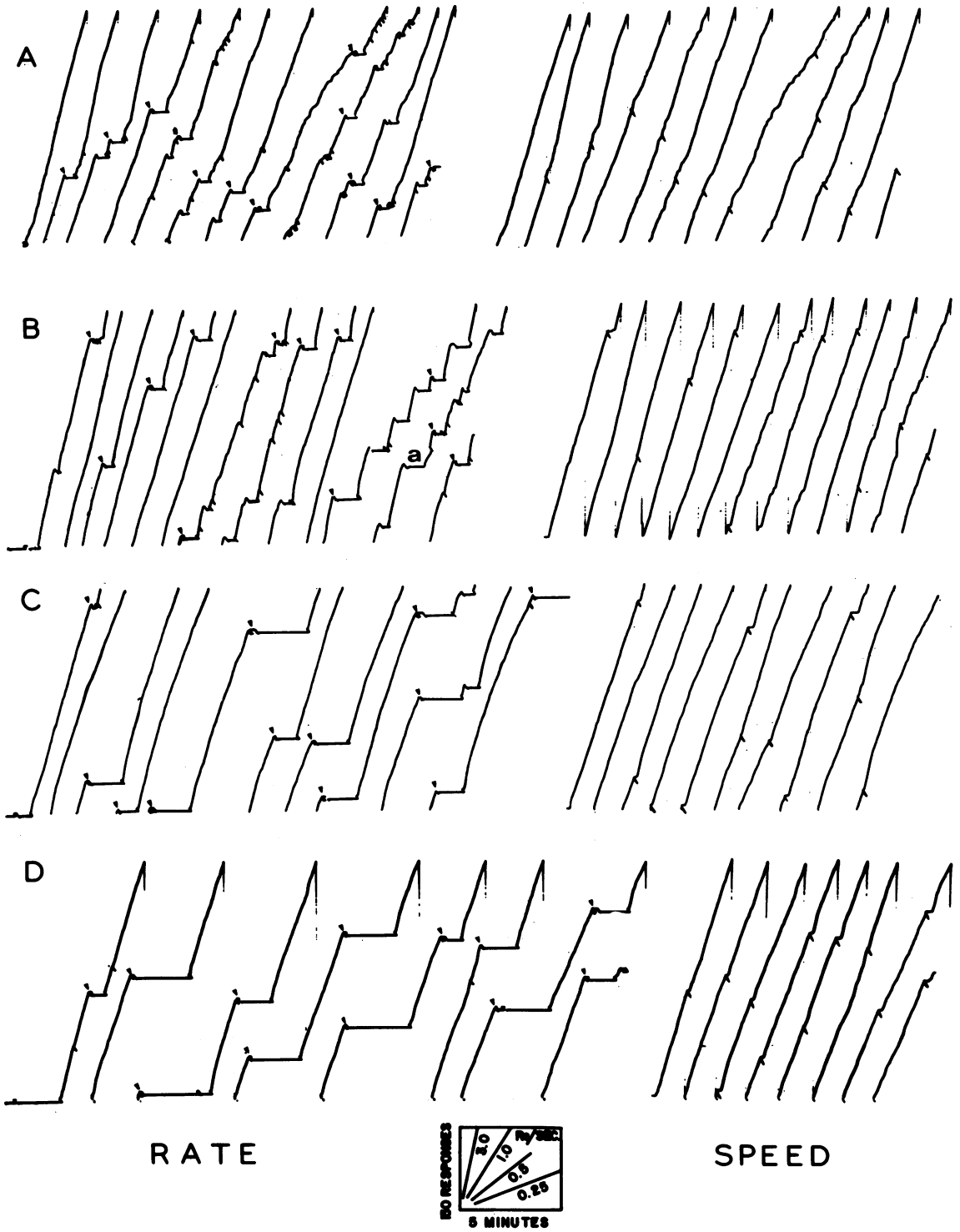


Fig. 8. Rate and corresponding speed cumulative records of development of stable state FI 5-min following FI 1-min for P-123. Rows A, B, C, and D are of sessions 2, 23, 49, and 154 respectively.

in some intervals, and instances of flickering within intervals also occurred. Previously, during FI 1-min, flickering was restricted to the PRP (see Figure 4).

The left side of Section B shows the rate record from Session 23. In the first third of the session, the rate record still displays short PRPs and a linear pattern of responding throughout the remainder of each interreinforcement interval. As the session progressed, the frequency of short off-platform pauses increased to the point that many such pauses were occurring throughout each interval. These pauses were often preceded by negative acceleration. Flickering was much reduced relative to earlier sessions. A long period of off-platform key pecking can be seen at point *a* of the record. All of these effects—multiple pausing, negative acceleration, increase and eventual decrease in flickering, off-platform key pecking—were also observed in the early transition from VI 5-min to VI 10-min (see Figure 7).

The left side of Section C (Figure 8) shows the rate record from Session 49. PRPs were longer, slight negative acceleration occurred throughout each interval, and an occasional knee followed by an off-platform pause was present. Flickering, multiple pausing within intervals, and off-platform key pecking were now absent.

The left side of Section D shows the rate record from Session 154. By this session the behavior had attained its stable state. The duration of the PRPs had increased. Negative acceleration within intervals was now very slight, and the record conforms to the break-run pattern typical of the stable state for FI 5-min (see Figure 4).

The speed records corresponding to the above rate records reveal that, except for some negative acceleration within intervals (especially in the early sessions of FI 5-min), speed was generally constant throughout each session. The above developmental changes in rate were, therefore, due more to changes in propensity than to changes in speed. This is similar to the transition from VI 5-min to VI 10-min, during which speed remained fairly constant throughout each session even though rate patterns were changing within sessions.

Figure 9 shows selected segments of interfeeder response-rate patterns during transi-

tional FI 5-min performance for P-121. Many of the segments indicate three successive behavioral states within the interfeeder interval. The first state is the postreinforcement pause which involves behaviors that occur off the platform. The second state is a boundary state which involves behavioral patterns such as knees, scalloping, rough grain, on-platform pausing, and flickering. Finally, the third state is the "run" or high, steady rate of key pecking prior to reinforcement. As terminal FI 5-min performance developed, the patterns generally demonstrated the two-state break-run pattern described by Schneider (1969).

The behavioral transitions between different VR and FR reinforcement frequencies are very simple to describe, and, therefore, no figures showing them are presented. When reinforcement frequency decreased, PRP length increased. When reinforcement frequency increased, PRP length decreased. Speed remained very constant within sessions.

*Extinction.* After the return to the initial VI 1-min, FI 1-min, VR 100, and FR 100 schedules, sessions of extinction were carried out (see Figures 1 through 3).

Figure 10 shows rate and speed records for later sessions of VI extinction for two birds. Note that as extinction progressed, the off-platform pauses in the rate records became increasingly longer. Negative acceleration in speed was very slight for P-112, and the termination of the speed record was rather abrupt. In contrast, P-113 showed marked negative curvature in speed and terminated the session standing on the platform. Off-platform key pecking can also be seen at point *a* in the record. The rate pattern during VI extinction for P-113 is more typical of VI extinction results reported previously than is that for P-112 (Ferster & Skinner, 1957, pp. 346-351).

Figure 11 shows rate records of Sessions 1, 2, 4, and 5 of FI extinction for P-123. During Session 1, rate was initially quite linear. Then periods of slight negative acceleration followed by short off-platform pauses occurred—an effect similar to the within-interval multiple pausing effect observed in the transition to FI 5-min from FI 1-min (see Section B of Figure 8). In general, over sessions the periods of steady responding became shorter and the pauses became longer, although several series of very short pauses occurred in the last

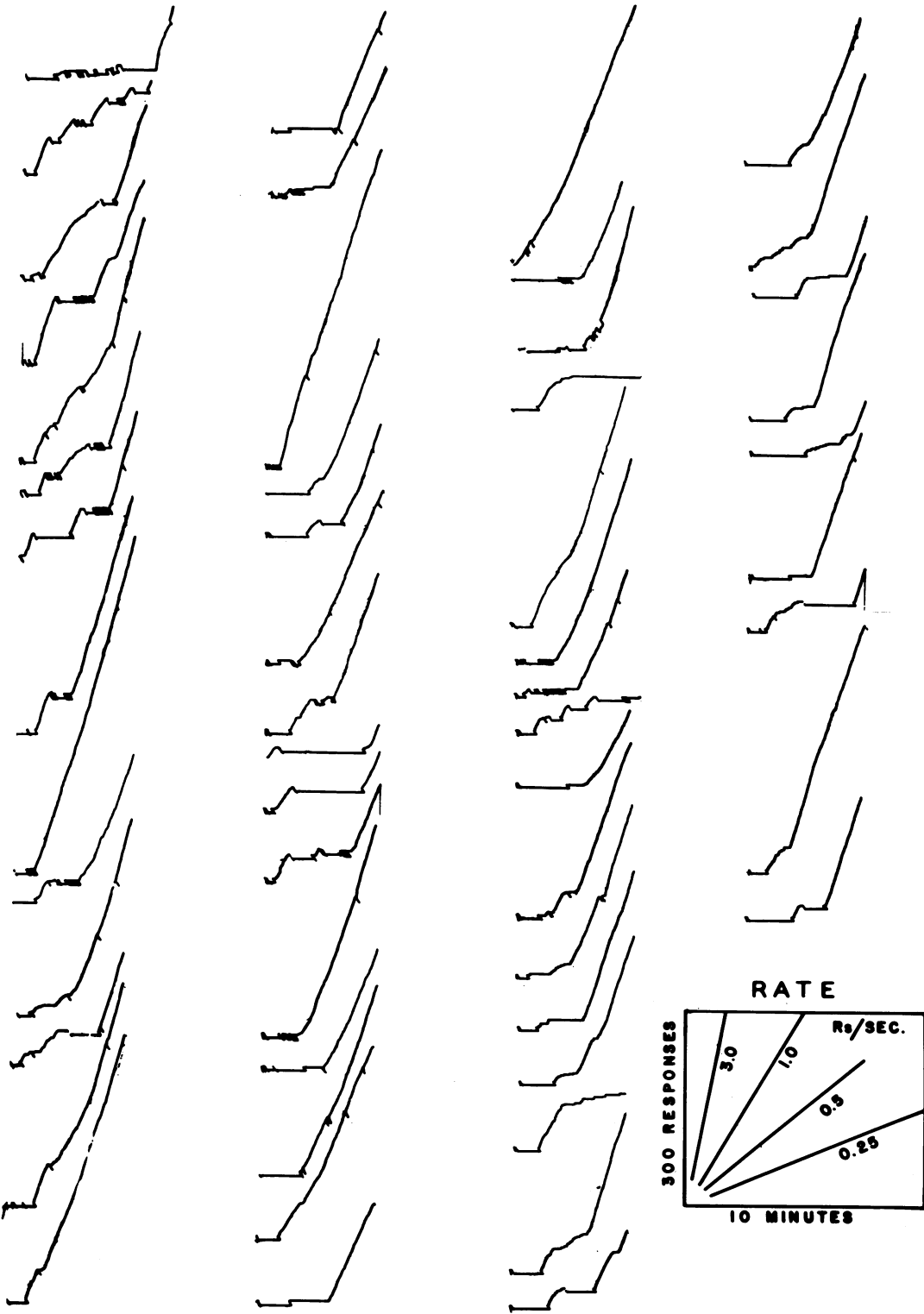


Fig. 9. Selected segments of interfeeder response-rate patterns during transitional FI 5-min performance for P-121.



two sessions. Note that virtually all pausing occurred off the platform. On Session 6, the bird did not peck the key or stand on the platform at all.

Figure 12 shows speed records of Sessions 1 through 5 of FI extinction for P-123. Note the extremely linear pattern that occurred with speed despite the variations in rate that were

seen in Figure 11. The short periods of negative acceleration seen in the rate records are still present, of course, but are somewhat less conspicuous because the off-platform pauses following them are not present in the speed records.

Although speed remained very linear throughout FI extinction for P-123, it was

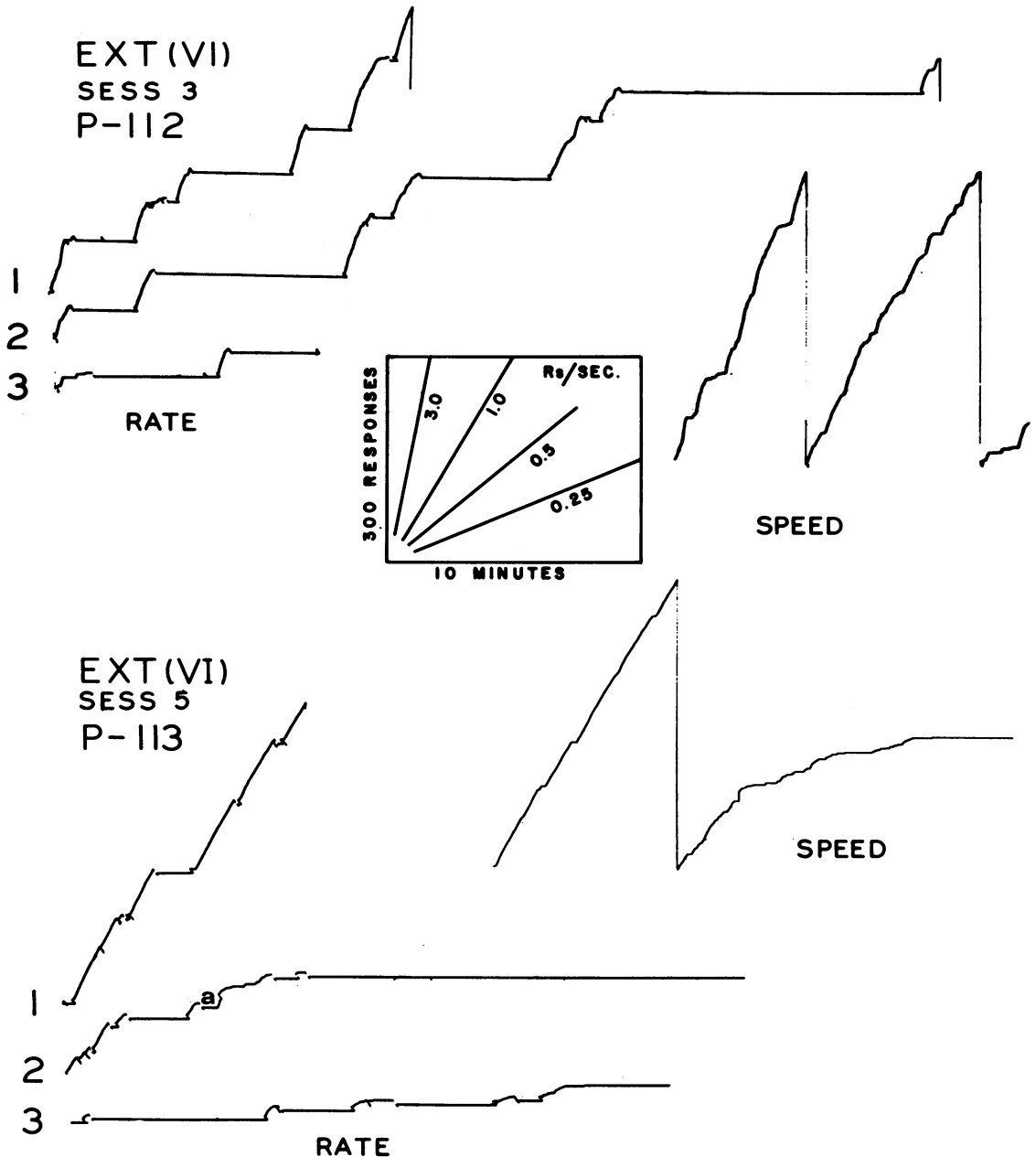


Fig. 10. Rate and corresponding speed cumulative records of individual extinction sessions for P-112 and P-113.

linear only during the first few sessions of FI-extinction for P-121. Then, as extinction progressed, negative acceleration, followed by periods of on-platform pausing and off-platform key pecking, occurred. On-platform pausing then decreased and, along with key pecking, disappeared after Session 13.

The rate records of VR extinction and FR extinction can be summarized by stating that a linear pattern of responding gradually gave way to increasingly longer off-platform pauses as extinction progressed. Very little on-platform pausing and off-platform key pecking occurred. Speed remained linear throughout most of the sessions. For both VR and FR extinction, a slight negative acceleration occurred in speed, just before the termination of key pecking.

DISCUSSION

The method used in this study separated out two constituents of response rate—speed and

propensity—and thereby provided new information concerning fundamental behavioral processes occurring during reinforcement schedules. The within-session data, which replicated response rate patterns obtained in previous studies on reinforcement schedules, consistently demonstrated that two behavioral states can be quantified in schedule research: (a) the emission of the experimentally reinforced activity and (b) the emission of other, alternative, activities. In addition, reflecting the continuous nature of behavior, it appears that between these two states there exists clearly identifiable “boundary states” which were manifested in the cumulative response records in several ways: (a) in “flickering” (rapid on-platform/off-platform oscillations); (b) in short periods of on-platform pausing at the end of FI and FR PRPs (during which components of the key-pecking activity, short of actual key pecks, occurred); (c) in on-platform pausing, typically preceded by negative acceleration in speed, during extinction (ap-

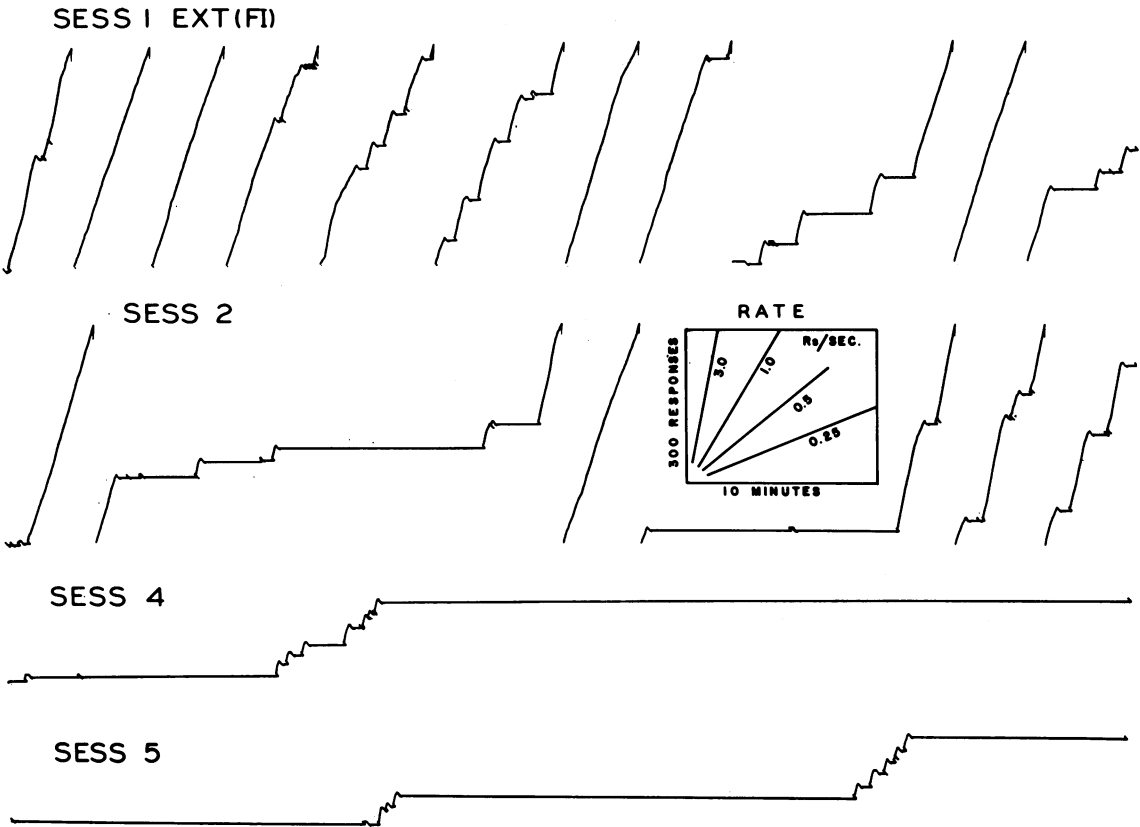


Fig. 11. Rate cumulative records of extinction sessions following stable state FI 1-min performance of P-123.

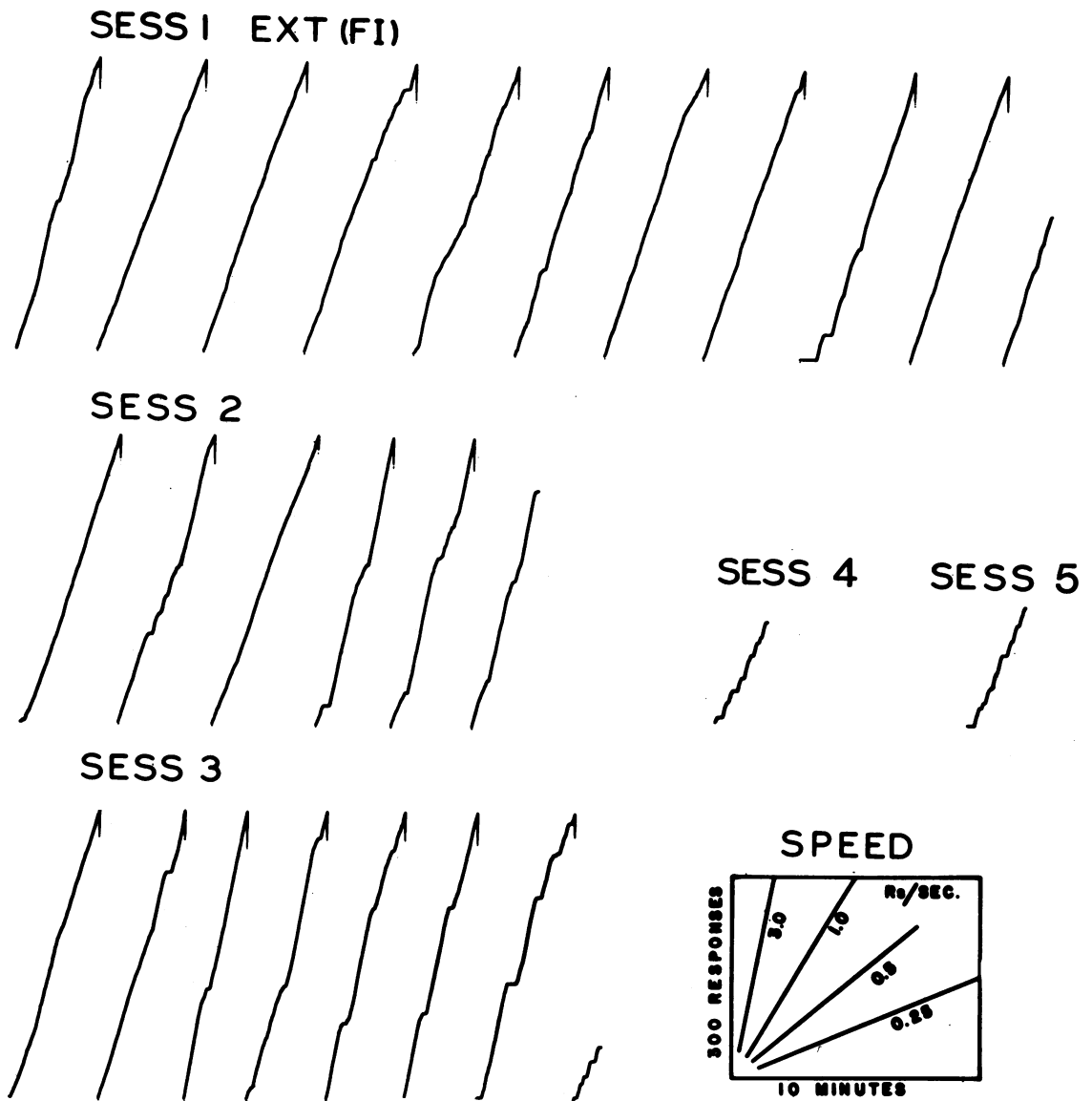


Fig. 12. Speed cumulative records of extinction sessions following stable state FI 1-min performance of P-123.

parently due to changes in the topography of the key-pecking activity as the propensity for the activity approached zero).

Interesting within-session effects, pertaining to the two main classes of activities and the boundary states between them, were observed both after prolonged exposure to the various schedules and during transitions when the behavior was adjusting from a higher to a lower reinforcement frequency. During steady-state

performance at the higher reinforcement frequency, most pausing was restricted to the period immediately following reinforcement (thus constituting the period termed the PRP) and occurred mainly off the platform. Flickering was common during the PRP, especially on the richer FI schedule, and rarely occurred at other times. Speed was very constant within sessions and off-platform key pecking was extremely rare. With sudden decreases in

VR and FR reinforcement frequency, the only major result, which occurred rapidly with FR and more gradually with VR, was increased off-platform pausing. Immediately following sudden decreases in VI and FI reinforcement frequency, however, not only were there increased instances of off-platform pausing, but off-platform key pecking also occurred more frequently, flickering sometimes occurred throughout an interreinforcement interval, and speed often showed negative acceleration preceding a pause. After prolonged exposure to the lower reinforcement frequency, provided that it was greater than zero, these "perturbations" disappeared as stable patterns of responding were recovered. Similar effects occurred when reinforcement frequency was decreased to zero (i.e., during extinction) except that off-platform pausing steadily increased in duration until propensity reached zero. For the birds that had been exposed to VR or FR schedules and for some of the birds that had been exposed to VI or FI, speed remained very nearly constant within sessions almost up to the point at which propensity reached zero. For the other VI and FI birds, speed showed gradual negative acceleration as propensity approached zero during extinction. While the small number of birds participating in the study precludes making many definitive comparisons between the within-session effects of the various schedules investigated, the within-session similarities across schedules indicate that reduction in reinforcement frequency can have pronounced disruptive effects which show up in the boundary states between the experimentally reinforced activity and other activities in which the bird engages.

The overall session-to-session data for propensity exhibited two important effects that were highly consistent within and across the four basic types of schedules examined, whereas the overall session-to-session data for speed and rate were considerably less consistent in these effects: (a) when reinforcement frequency was markedly decreased, propensity decreased (although the time required for the decrease to occur differed between different types of schedules); (b) a return to a higher reinforcement frequency produced a return in propensity to or near the original level under that reinforcement frequency.

There were also some highly consistent over-

all session-to-session differences between schedules in propensity but not in speed or rate:

1. The stable state levels of propensity during VI were consistently higher than the stable state levels of propensity during FI.

2. Under VI propensity always changed immediately (if at all) in the direction of the change in reinforcement frequency, whereas under FI the initial effect was always an increase regardless of the direction in which reinforcement frequency was changed.

3. Decreases in VI reinforcement frequency produced smaller initial changes in propensity and smaller increases in its variability than did similar decreases in FI reinforcement frequency.

4. Propensity reached its stable-state level much more rapidly after a change in VI reinforcement frequency than after a similar change in FI reinforcement frequency.

Since the VR and FR schedules were each examined with only one bird, no attempt will be made here to discuss differential overall session-to-session effects these schedules had with respect to each other or the other two basic types of schedules examined.

In accounting for the higher propensities obtained with VI than with FI schedules, it might be noted that the 8-sec COD used in this study imposed a more stringent contingency for staying on the platform under VI than under FI. In the latter case a bird could remain off the platform for a considerable amount of time after reinforcement without delaying the occurrence of the next reinforcement whereas in the former case this would not necessarily be true. However, sustained performance under VI was also obtained by Ferster and Skinner (1957, pp. 334-339) whose method did not, of course, involve anything resembling a COD between activities. Therefore, it seems likely that the variable delivery of reinforcement rather than the COD was the factor responsible for the high propensity levels obtained with the VI schedules in the present study.

Some of the overall response-rate data obtained with the VI data, however, did appear incongruent with data obtained in previous studies. In the present study, on the one hand, no consistent relationship was found between stable state response rate and VI reinforcement

frequency at the values examined above zero. Previous research, on the other hand, suggests that response rate during the stable state is a negatively accelerated, monotonically increasing function of VI reinforcement frequency (e.g., Catania & Reynolds, 1968). In addressing this difference, note that standard schedules do not explicitly specify for reinforcement any components of the experimentally reinforced activity other than the terminal component, which, in the case of key pecking is, of course, the key peck itself. This means that wide variations in the components of the activity are likely to be "adventitiously" reinforced in standard VI schedules, particularly when the reinforcement frequency is fairly low. Thus, Hearst (1969) observed that pigeon's key pecking was largely restricted to quite stereotypic back-and-forth head movements during relatively rich VI schedules but involved extended chains under lower reinforcement frequencies. In the latter case, the bird might often, for example, circle the chamber and nod repetitively before pecking the key. If such chains tend to increase in length as VI reinforcement frequency decreases, this may account to a large extent for the type of functional relationships typically found between response rate and VI reinforcement frequency (cf. Blough & Blough, 1968). The COD procedure used in the present study, however, prevented the extensive development of such complex chains, even at very low reinforcement frequencies, since reinforcement could not follow any behavior which occurred off the platform by less than eight seconds. However, it was still possible for the topography of the on-platform behavior to change. These behavioral changes occurred and appeared to have affected unsystematically the overall speed and rate functions of the present study.

Changes in the topography of the experimentally reinforced activity that change speed, and hence response rate, impose serious limitations on the possibility of developing quantitative laws of behavior simply on the basis of response rate. A change in rate may not always reflect a change in the probability of the entire operant unit but only a topographical change within the unit. Our findings and those of others (e.g., Hawkes & Shimp, 1975) argue strongly for basing quantitative formulations on descriptions of the

operant unit that are more complete than that provided by response rate. In this connection, it might be noted that topographical changes in an activity would not be expected to affect its propensity—at least not as strongly as they affect its speed and response rate. Consistent with this observation is that propensity on all schedules in the present study showed highly consistent changes as a function of reinforcement frequency, while speed usually "drifted" in every possible manner. This suggests that time measures will be important in formulating general laws of behavior; however, the variations in speed observed in this study also suggest that such laws must also incorporate the topographical or structural variations in the operant unit.

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Received August 8, 1978

Final acceptance April 30, 1979